THE USE OF FRESHWATER SCIENCE IN POLICY DEVELOPMENT

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Introduction

The Chambers Dictionary of Science and Technology defines "science" as "*The ordered arrangement of ascertained knowledge, including the methods by which such knowledge is extended and the criteria by which its truth is tested*". For the term "policy", the Concise Oxford Dictionary provides an initial definition of a "…*course or general plan of action (to be) adopted by a government, party, person, etc*". Of course, for many of us, it would naturally follow that science, or "…*ascertained knowledge*…", would be the backbone of policy development, or the formation of principles to guide action. However, the seamless application of science to policy-making remains far from the norm.

This article explores the diversity of scientific disciplines and paradigms, their relevance for policy development, how policy emerges throughout society, and the mechanisms by which scientists can promote the value of science in policy formation.

Scientific paradigms

Kuhn (1962) coined the term "paradigm" to describe the formation of scientific frameworks. Khatibi (2002) reflects that science itself has been through three paradigms: reductive science, holism and systems thinking.

The first of these paradigms, *reductive science*, was developed during the Industrial Revolution (mid-18th to mid-20th Century) and has been described as "…*the most successful explanatory technique that has ever been used in science*" (Medawar & Medawar 1977). It involves reducing complex systems to their component parts as a means of developing understanding. For example, a problem of urban flooding may be examined using one or more of the following disciplines (FIG. 1):

- The engineer may utilise hydrological and materials sciences to deliver a traditional "hard engineering" flood defence solution to handle flood peaks occurring at a predicted frequency.

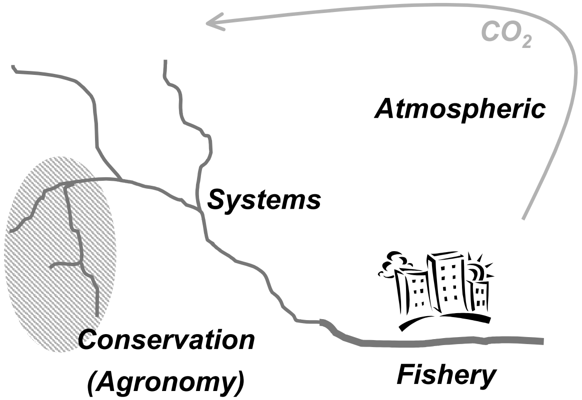

FIG. 1. The perspectives of different types of scientist upon an urban flooding issue.

- The fishery scientist providing input to this scheme may use the sciences of hydraulics and fish swimming rates to help plan deflectors, groynes, sinuosity and other measures to mitigate habitat loss.
- The atmospheric scientist may perceive the problem as lying in the rising levels of greenhouse gases and their implications for climate change.
- The conservationist may be inclined towards the views of the systems scientist, recognising the higher conservation value of habitat in non-industrialised areas of the catchment, and promoting their protection and/or restoration to deliver wildlife gain and social benefits as a form of mitigation for downstream "hard" flood defences.
- Meanwhile, the agronomist, also utilising robust scientific principles within their own discipline, might be addressing food needs in the urban area in part by developing plans for the drainage of those same upstream habitats to maximise their agricultural productivity.

These provide a number of different perspectives on the same system.

Throughout the Industrial Revolution, reductive science acted as a key to opening up new understandings about natural systems and our capacities to exploit them. In the UK, the unequal share of education, land ownership and wealth encompassed by class structures led to an easy acceptance of what was deemed to be "right" as perceived by an elite, and science held an elevated position in the formation of policy. It may still have retained something of that position as late as the 1960s – the boom of publicly-funded university-building in the UK – when policy and investment were driven and fuelled by the promise of "…*the white heat of technology*".

Associated with this was the development of the traditional perception of science as being objective and value-free. However, there is a growing consensus rejecting this premise. Cortner (2000) summarises literature demonstrating that subjective value-interpretations are made routinely in science in defining problems, framing hypotheses, choosing methodological design and making methodological assumptions, selecting criteria for analysis, building and running computer models, and interpreting results. Experimental design often demands that research questions are narrowly defined, itself introducing subjective bias, as do the classification schemes chosen for statistical analysis. Porritt (2000) extends these arguments, calling into question the extent to which the rise of multinational companies as the major source of science funding globally has further compromised the objectivity of science, and has contributed to the observed decline in public trust of scientists. Of course, scientists work to eliminate bias, but through these factors it remains. The public may look to science for certainty and solutions, however Cortner (2000) contends that since science is about the establishment of theory, the perception that it offers objective and unbiased truth is necessarily flawed. Furthermore, politicians can manipulate science by calling for research to postpone decisions (Cortner 2000), or selecting only certain strands of science upon which to frame decisions, promoting this as fully objective opinion. As Ken Collins, former Chairman of the European Parliament Environment Committee, reported of his experience with managing the BSE epidemic, "*…he was astonished at how often 'scientific' views came with 'national labels' attached. It is not surprising that 'science' impresses regulators rather less today than 10 years ago*" (ECPI 1999). Indeed, the choice of "hot topics" for research funding is itself a political decision, with the decision to ask a question itself value-laden as well as scientific.

The second paradigm has been that, "…*Since the 1940s, science has increasingly embraced 'holism'*…" (Khatibi 2002), this being based on the General Systems Theory presented by Bertalanffy (1940). In this paradigm, the connections between disciplines are highlighted, together with the need – apparently at odds with reductionists – to think in multidisciplinary terms. In the urban flooding example above, the different perspectives described are drawn together to form a balanced view and a basis for more holistic and sustainable action.

The third and current paradigm is *systems thinking*, based on understanding the properties of systems as a whole and the relationships of their components, which Vickers (1981) says removes the "*apparent antithesis*" between reductionism and holism. The emphasis is upon patterns and relationships within complex systems, which cannot necessarily be deduced by analysis of their constituent parts. Everard &

Powell (2002) explain the relevance of systems thinking to the management of the water environment. In the example given above (FIG. 1), the systems scientist would use hydrological, chemical, habitat, climate and other branches of science to determine overall flood conveyance, and to investigate ways of detaining flood peaks by measures "upstream" in the catchment that also provide conservation, water quality, landscape and amenity benefits.

Utilising science in the development of policy

In recognising these paradigm shifts, it is important also to emphasise that the time for curiosity-led research is far from over. Indeed, it is the very seedcorn from which tomorrow's understanding and technological applications may arise. However, when using science to inform policy, the context in which that science is cast is everything.

The "hard" biophysical sciences encompass only a proportion of the whole body of science, in the sense either of "…*ascertained knowledge*…" or of "…*the methods by which such knowledge is extended*". Today, the direct application of hard reductive science without also taking account of the other "softer" forms of science – applied as opposed to pure science, and the economic, social and political sciences – has attracted legitimate criticism (Porritt 2000). The apparent imposition of novel environmental standards for chemicals, without adequately addressing risk, uncertainty, enforceability and the economic and political implications of their introduction, is a pertinent current example.

Furthermore, science alone offers only single sets of values within a greater set of both tangible and intangible values from which society's direction and supporting policies emerge. Imposition of policy without reference to these other sectors of society – its values and beliefs, economic activity, legislation and personal freedom – would be seen today as undemocratic and so we cannot rely upon the arguments of sound science alone to persuade the rest of society or its policy-makers. Human rights issues are brought into question when people perceive themselves as being "told by scientists" how we are to deal with GMOs, BSE, and other complex issues (Grove-White et al. 2001), not to mention examples from the past century of the perceived uncontrolled application of science to eugenics and cloning. All of these factors contribute to the current mistrust of scientists in government and regulatory organisations (Grove-White et al. 2001; Porritt 2000).

Science has to be set into this societal context, and to be translated into terms relevant and comprehensible to the public, if it is to guide policy effectively. In considering the evolution of policy with respect to river

conservation, Palmer et al. (2000) note that "*Ultimately, it is in legal structures that society expresses its values, and environmental conservation is one of the emerging values of the late 20th century*", and Pollard & Huxham (1998) define the goal of sustainable development legislation as promoting the "…*constructive interplay of sound ecological science and societal values which ensures ecological integrity and allows a sustainable yield of ecosystem goods and services*". Science alone, if perceived as occupying an "ivory tower", will have little leverage upon legislation or non-regulative policies, since it does not operate as a society-wide value system. However, science offers a unique capacity to inform wise-use policies which can be developed as appropriate to the needs and aspirations of local people (IIED 1994; Everard et al. 1995). The goal then is to make transparent to society the values that the science illuminates, and to apply these through advocacy as well as informing concerns expressed through other sectors of society.

It is evident that the paradigm shifts of science itself need to be translated through to the mechanisms for its application to policy.

Mechanisms for promoting science in policy formation

Cortner (2000) identifies conservation biology and natural resource management as stemming from the new and systemic multi-sectoral approach to science that also takes account of local economies, value judgements, and a range of social factors in addition to "hard" ecological science. Of course, the Ramsar Convention (Ramsar 1971) itself, with its principle of "Wise Use", embodies a view of wetland ecosystems and their conservation that is integral to their value in supporting the livelihoods and life aspirations of the human populations that depend upon them. Contrary to many current approaches to sustainable development, however, it is not enough to pull together arbitrary economic, ecological or social elements of an issue and to claim that these represent a strategic approach to the achievement of sustainability. Methods of effective engagement of different sectors of society and holistic frameworks for systems thinking are essential for the development of integrated and effective policy.

Our old approach to public understanding of science – spending effort seeking to relay difficult scientific principles to a lay public – may not be enough to affect the values of society. Scientists' understanding of the public, and their often unscientific concerns and aspirations, may be a more important consideration if we are to begin to seek to influence public policy. This will enable us to be less purely "scientific" in the ways we help the public to understand the implications of scientific principles that impinge upon their daily lives. Pertinent examples include efforts to influence thinking about the dependence of business upon biospheric "services" (e.g. Everard 2000a) or of fisheries upon the systemic health of whole catchments (e.g. Everard 2000b; 2001a), and the need for more sustainable use of timber by guitarists and guitar manufacturers due to the parlous state of the world's remaining rainforest ecosystems (Everard 2001b). There is at present a worrying shortfall in formal recognition of the need for and the funding of effective science communicators and advocates, which currently relies upon the enthusiasm of individuals and the actions of some generally poorly-funded non-government organisations (NGOs). Yet this lack of translation skills and capacity may harm the perception of science and scientists, if not addressed, and undermine the public funding of science. The new paradigm in which we live calls for far more fluent communication between all sectors of society.

Shannon & Antypas (1996) used the term "civic science" to describe this democratisation of science, noting that "…*civic science involves scientists as citizens and citizens as lay scientists in a process in which knowledge production is integrated*…", the whole being aimed at enlightenment and the moral effects of the use of science. This is at odds with the previous "objective science" paradigm in which scientists were not held accountable for moral implications stemming from reductive science. Both Cortner (2000) and Porritt (2000) advocate the extension of civic science, emphasising the importance of democratising expert cultures and the importance of collective learning amongst participants from all sectors of society.

This approach requires a good understanding of how society works as a complex system – a system that will of course operate in different ways across the globe – as well as an effective means for outreach to those other parts of society. Reductive thinking would have us believe that the academic sector is the major source of new scientific ideas, which may enter the private sector in terms of new technologies and the public sector in terms of new policy. The systemic reality is somewhat different, however, and includes issues such as multinational funding of science and the political decisions inherent in the direction of science as touched upon above.

Freshwater science and policy

Within the context of fresh waters, rivers force an integrated approach since they touch upon all aspects of human activities, cross geo-political boundaries and interact with both terrestrial and marine ecosystems. Integrated management initiatives come more frequently from the aquatic than the terrestrial perspective (Palmer et al. 2000). However, true integrated science "…*involves more than assembling massive collections of data joined only by the staples that hold the final report together*" (Clark et al. 1995, cited in Cortner 2000), requiring appropriate methods of collation of topics and tools for participation (Calder 1999). The case studies outlined in Box 1 provide examples, both positive and negative, of the application of the principles already discussed to the freshwater environment.

A number of clear principles emerge from these few brief case-studies about the use of freshwater science in informing policy. Firstly, sound science is essential as a foundation for thinking. However, those scientific principles are only one aspect of the varied considerations that make for successful policy formation. It is important to understand the breadth of values that society weighs in the formation of policy, and also to seek to articulate the implications of science upon the day-to-day lives and expectations of society so that these can be entered into value systems. For example, the fact that the depressed river mussel (*Pseudanodonta complanata*) – a critically-endangered species at UK and European scales – is endangered, is not of itself persuasive to most people. Nor is the rarity of the species perceived as a reason to divert expenditure from hospital beds, urban regeneration or military hardware. This is not merely due to the sad fact that the depressed river mussel is only one within a queue of literally dozens of equally-endangered species requiring urgent conservation action, but because a statement of rarity in isolation lacks an holistic context that connects with wider values and achievement of the common good. It is therefore hardly surprising that it is not persuasive in policy terms. Such a context could be provided, however, by taking a systems view of biodiversity (Everard et al. 2001) and pointing out that it is the sole indicator of the health of ecosytems, which provide the *ecosystem functions* that not only support life, but also provide the bulk of economic goods and "quality of life" from which people are able to reach their potential. This view gives a context to the science to which other sectors of society can identify, and it creates a publicly-comprehensible vehicle through which the conservation of the depressed river mussel can be incorporated into policy.

Scientists must seek to frame problems in broad terms, as narrow definitions will inevitably deliver technical solutions that are more likely to be parochial and unsustainable. The development of more sustainable policies must necessarily utilise systemic conceptual tools, and it is also essential that these tools are also *used* in systemic ways. Any understanding of the water environment, as indeed any other ecosystem, must recognise the human as an integral part of the ecosystem, in terms both of its impacts and reliance upon that system. This means that economic

Box 1. Case studies illustrating the success or otherwise of using freshwater science to inform policy.

1. **Integrated Catchment Management Systems** (ICMS) provide an inclusive approach to the application of science to policy at the catchment scale (Calder 1999). To date, however, despite the visionary and systemic intellectual basis of ICMS, many saw early implementation as "…*little more than tedious paperwork aggregating disparate, poorly-integrated plans with no strategic vision*" (Everard et al. 2001). Worse still, early implementation of ICMS in the UK and elsewhere was frequently overburdened by technical detail beyond the grasp of the lay person, and the options upon which "consultation" was purportedly based were limited and the outcome already foregone due to prior investment decisions. The systemic tool had in effect been applied in a reductive mode, collating the opinions of technocrats with little serious scope for wider dialogue. The principle of ICMS as a framework for applying science and democratising decisions remains robust, though we have perhaps failed to realise its promise due to the ways in which it has been applied. Some of this systemic approach has been applied more successfully to thinking about the sustainable development (or Wise Use) of wetlands under the Ramsar Convention (see main text).
2. **Asset Management Planning (AMP)** – the water industry investment mechanism in England and Wales – provides an example of a policy instrument "stuck" in the reductive mode, using a narrow definition of water quality problems that inevitably leads to narrow, and generally unsustainable, "hard" engineering solutions (Everard & Porritt 1997). The EU Water Framework Directive (WFD) is set in a more helpful systemic perspective, providing a goal-oriented outcome of *good ecological quality* and offering the promise of more systemic solutions that include balancing diffuse sources of pollution with point source controls, habitat enhancement etc. Like ICMS, the WFD establishes great promise, framed within an appropriate paradigm. We await its practical effect upon the water environment of Europe, which may be significant if applied systemically, but which will be compromised if constrained by narrow reductive implementation.
3. A systems-based study of the **recovery and sustainable use of phosphorus from liquid effluent** by Everard (2001c) compares current linear use of the substance with natural cycling. Current patterns of human usage of phosphorus lead to aquatic eutrophication, the wastage of refined phosphorus, and wastage also of the material and energy inputs entailed in extraction, processing and transport, with associated social impacts. More sustainable use could be achieved through recovery from effluent and sludge, best agricultural practices, reducing the content in domestic products, continuing eco-efficiency of industry and recovery of phosphorus from power generation and incineration. However, the low cost of virgin mined phosphorus and inadequate controls on usage by society perpetuate today's patterns of use and lead to problems "downstream" in the process. The narrow and parochial policy definition of eutrophication also contributes to non-systemic solutions to pollution control. Collectively, these contribute to the linear flow of phosphorus and associated pollutants from mined resources through to accumulation in ecosystems, with associated loss of biodiversity and amenity.

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Box 1. ***(...continued)***

4. In Australia, there is an emphasis on linking research and the user in the management of the water environment, largely through **co-operative resource centres** (Professor Peter Cullen, reported in Sweeting 2001). This is based on an understanding that the cultures of the researcher and the user are different and that communication is consequently poor. Users, largely professionals in the water industry, are strong in engineering, economic and administrative skills, get most of their research knowledge through dialogue, and are interested in what is known already and how it affects their requirements. By contrast, the interests of researchers are what is not known, which they can then explore. Users fund the research, but this will depend upon a good understanding of how the research may fit their needs. The results of this mismatch are often suspicion, poorly-defined applied-research goals and inappropriate research reports. In the Australian co-operative resource centre model, transfer of knowledge is not seen as the researcher's job alone, but a co-operative task. To assist this, "knowledge brokers" are used to manage the interactions and to assist in translating the needs of the different partners. These "brokers" have some understanding of the science, the industry and the mechanisms, but their chief assets are inter-personal communication and resource investigation skills.
5. Palmer et al. (2000) note that the opportunity to revise completely the legal basis for the administration of water resources is rare, but that implementation of aquatic science to **water law in South Africa** provides a successful recent example. Here it proved essential to communicate basic scientific concepts to lawyers and water resource managers, including aspects of geomorphological and hydrological processes, water quantity, geology and topography, channel form, the availability of a range of physical and hydraulic habitats, and the role of these habitats as an abiotic template for biotic diversity. These disciplines have also to be understood in relation to the ways that humans may influence them, the role of the catchment as the unit of legislation and management, and the social and economic values that interact with the environmental values in decision-making. This then provides a powerful tool in determining legal content and in generating the political and moral will of the legislators (Hart 1984). Perhaps the main indicator of this success is the establishment of the key principle from a river conservation perspective, which reads "*The quantity, quality and reliability of water required to maintain the ecological functions on which humans depend shall be reserved so that the human use of water does not individually or cumulatively compromise the long term sustainability of aquatic and associated ecosystems*". This articulation is clearly informed by systemic and robust science, but expressed in terms relevant to the realisation of the common benefit of all.
6. **The continued use of peat in horticulture and gardening**, still actively promoted in retail outlets and the media in the UK, remains a depressing reminder of the failure of the community of aquatic scientists and conservationists substantially to change policy. This is in spite of high-profile campaigns in previous decades, that somehow failed to link the public consciousness of peat extraction with anything other than an intangible value remote from other day-to-day decisions. The horticultural trade is itself also responsible for the continual flow of exotic species, foreign strains and genetically-manipulated varieties into the UK, with all the associated risks of introducing new weed species and compromising the genetic integrity of native biota. Yet the manifest scientific risks seem not to feature at all in the public value system.

pressures are a substantive part of the functioning of the total ecosystem, as for example in the non-utilisation of "waste" phosphorus from effluent when mined virgin-phosphorus remains so cheap. The challenge of increasing the contribution of science to policy is great, and will require us to reconsider the ways we think about our science.

Other implications for science

There are clear implications from this article for the spending of public money on aquatic and other branches of science. Lawton (2001) stated that "*We cannot just consider science, rather we have to work in partnership with the social, legal and economic agendas. There is no question about that and it is a new world for scientists to find ourselves in if we are going to take part in delivering a sustainable future*." To this he added the important rider that, "*However, when we do science, it manifestly has to be independent and it has to be the best science we can do*." All research councils and other bodies funding science will need to take note of this new paradigm. Those charged with funding freshwater science are no exceptions, athough as noted previously, systemic approaches are more advanced amongst those working in the aquatic environment.

However, in reconsidering the ways we think about our science, perhaps the most difficult element of all for scientists is acceptance of "unscientific" compromises and trade-offs. Yet the recent example of agreements to limit greenhouse-gas emissions emphasises the value of such compromises. Upon securing agreement at the Bonn renegotiations of the Kyoto Protocol in July 2001, EU delegation chief Olivier Deleuze said, "*We would have preferred to have fewer sinks in the deal… …I could give you ten examples of changes I'd like to have seen. But I prefer an imperfect living agreement to a perfect one that doesn't exist*" (reported in ENDS 2001). Whilst such trade-offs do not fit easily with our purist scientific tradition, the outcome is better than continued inactivity in curtailing emissions.

Final comments

Elementary biophysical science informs us that there is nothing democratic about the finite limits of the Earth's supportive capacities. Science illuminates the clear implications for society of the stresses it places on the ecological systems upon which it depends. The implications for our future collective well-being, stemming from observations of rates of loss of species, habitats and ecosystem services, water scarcity, eutrophication and climate change – to name just a few of the more worrying trends directly impacting freshwater systems – offer immediate warnings to policy-

makers. However, reductive science is no longer an unquestioned basis for policy formation. It is necessary for scientists to recognise today's systemic paradigm.

It goes without question that the science selected for informing policy should be *robust*; or in other words "sound science". However, we must also ensure that different scientific perspectives are selected as *appropriate* to the problem and to the scale at which it should be addressed, and that it is adequately *tested* by other scientists so that inherent biases can be resolved to some form of consensus. We must also recognise that the formation of public policy is in effect an articulation of the values held by that society, and so the translation of science to *social value* is an important – and currently massively under-funded – link in the chain of the application of science. The voluntary or NGO sector of society may have an important contribution to make in filling that gap, reflecting as it does wide-ranging concerns and special interests of society. The NGO sector is diverse and numerous. In the USA in 1996, there were at least 3,000 such bodies whose missions directly included river and watershed conservation, a total excluding the myriad "grassroots" groups as well as special-interest groups benefiting from the freshwater environment but with no explicit commitment towards its conservation (Karr et al. 2000). There is also a spectrum within the NGO sector ranging from the confrontational (e.g. *Surfers Against Sewage*) through special-interest groups (fishing clubs and local interests) to solutions-oriented organisations (e.g. *Forum for the Future*), including those founded upon the application of science to those solutions (e.g. *The Natural Step*). The existence of such a large body of opinion-formers demonstrates both the need for more effective translation of science into public values, and its current marginalisation from "mainstream" publicly-funded efforts to apply science to policy. Society can learn a great deal from the successes, as well as the shortfalls, of the NGO movement in precipitating more informed decisions about public policy.

It is no longer sufficient to rely upon traditional approaches to the utilisation of science. The lay public are unlikely to become aware of the significant implications of science from the peer-reviewed literature, and scientists often fail to pitch the science at a level appropriate for public understanding. Neither is the linear transfer of science from academics to policy-makers sufficient, through for example the *Parliamentary and Scientific Committee* and its journal *Science in Parliament*, which has the two main objectives of "*informing the scientific and industrial communities of activities within Parliament of a scientific nature and of the progress of relevant legislation",* and "*…to keep Members of Parliament abreast of scientific affairs*" (Parliamentary and Scientific Committee

2001). Scientific and political institutions in the UK and Europe are beginning to realise that they have no option but to democratise science and the means by which science is translated into public policy. This calls for a revolution in the way we think about our science, the efforts we expend and methods employed in communicating its implications to a wider public, and the way we engage with other sectors of society to drive forward more sustainable and scientifically-informed public policies. In short, we need to understand the value of science to society and to market it effectively.

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